VII.

ON THE INFLUENCE OF MAGNETIC STRESS UPON THE CAPACITY OF AN ELECTRIC CONDENSER.

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Recent work in the laboratory of the Worcester Institute of Industrial Science has apparently established results of which the following is a brief statement.

When an electric condenser placed between the poles of a powerful electro-magnet is charged and discharged through a galvanometer, its capacity as indicated by the swing of the needle is increased by the excitement of the magnet, if its lines of force are perpendicular to the plates of the condenser; but if the condenser plates are parallel to these lines, the capacity is diminished. The percentages of increase in one case and decrease in the other are equal in magnetic fields of the same intensity, and these variations from the normal capacity are greater as the intensity of the field increases.

The experiments which led to these conclusions were suggested by Maxwell's statements, which indicate a similarity of stress existing in the electro-static and electro-magnetic fields. Maxwell also says that in a field on which electro-static as well as electro-magnetic action is taking place, we must suppose the one stress superposed on the other.

Several methods of experiment were successively tried, and rejected on account of possible sources of error, before the final disposition of apparatus was reached.

The first trial was with a $\frac{1}{2}$ microfarad condenser placed on edge between the poles of an electro-magnet. The cores of the magnet were 2 inches in diameter and 13 inches long, and were united by a massive soft iron yoke. Each branch was wound with 275 convolutions of wire through which a current of 11 ampères was driven by a dynamo, about ten feet distant. Movable pole pieces were used, and by varying their distance from each other the intensity of the magnetic field could be increased or diminished at will. The current from the dynamo

measured by a large tangent galvanometer was approximately constant during the whole series of experiments.

This apparatus was placed in a basement about sixty feet from the testing-table on the floor above. A pair of carefully insulated wires made connection between the condenser and the testing-table. On the table was a Thomson reflecting galvanometer of 7,000 ohms resistance, and the charging key. A water battery was used to charge the condensers, and the charging potential varied at need from 3 to 175 volts.

The ½ microfarad condenser was charged and discharged through a plain key, the magnet being alternately excited and inactive.

Encouraging but not decisive indications were obtained. The variation was so small a part of the total capacity, that it was masked by errors of experiment and observation.

To reduce the deflection of the needle to a manageable amount and yet retain the same variation, if any, a new condenser of about the same capacity was made, and three keys used. By the first, both condensers were charged simultaneously to the same potential; by the second, they were discharged into each other; and by the third, the difference between their charges was discharged through the galvanometer.

The use of three keys was found to introduce great errors, arising from variations in the time given to each of the operations mentioned above, and a new key was made which required but a single motion instead of three. After adopting a uniform time of charging — in the majority of cases fifteen seconds — fairly constant results were obtained, and some of the earlier observations reported are taken from experiments in which this key was used. Ultimately on account of objections to the length of time of charging, as well as to secure greater uniformity in the separate periods allotted to each part of the process, a new key was constructed, which proved very satisfactory in use, and which has been employed exclusively since that time. It consisted of a heavy ¾-second pendulum furnished with adjustable catches, by whose use it could be made to execute a single vibration through any required amplitude, and could be held suspended at the end of its swing.

The pendulum carried on its under side two insulated metal pieces, from each of which depended three small platinum wires.

These wires in the course of their vibration cut through drops of mercury connected with the poles of the battery, the poles of the condensers, the binding-screws of the galvanometer, and each other, in such a manner as to produce the desired connections.

The amplitude of the vibration was fixed to give about one tenth of a second to the charging, one tenth of a second between the charge and discharge, and one tenth of a second to the discharge into each other, at last leaving the condenser plates in communication through the galvanometer.

The proper insulation of the wires at the key gave some trouble, but was at last secured by imbedding the wires in paraffine at all points of contact with the key, and placing the drops of mercury at the bottom of deep grooves in a paraffine block, separating those in the same groove from each other by a transverse groove of greater depth. In fairly dry weather, this arrangement gave satisfactory results. This key could be used to charge and discharge a single condenser; in fact, in the later experiments it was found better to use but one condenser, regulating its size to make the deflections manageable.

With the apparatus thus arranged and tested for connections and insulation, the labor of experiment was comparatively light. The condensers were charged and discharged several times, the electro-magnet meanwhile being inactive. The dynamo was then set in motion, the magnet excited, and the condensers charged and discharged as before. Usually this process was repeated several times before making any change in the apparatus, as will be seen in the tables which follow. Repeated tests were made to determine whether the dynamo or the electro-magnet by their direct action would affect the scale reading, but no motion of the index line could be detected when the machine was started and stopped by an assistant. This test was repeated, with the battery, condenser, and galvanometer circuits joined, in every combination assumed by them in the course of the experiment.

The magnet circuit was always closed. The charging battery was disconnected from the condensers $\frac{2}{10}$ of a second before the condensers were put upon the galvanometer.

In these experiments no attempt has been made to obtain accurate quantitative results, and as no care was taken to adjust the galvanometer to the same degree of sensitiveness, the readings in different series of experiments are not comparable.

The directive power of the earth upon the needle was very nearly neutralized by magnets placed near it, so that the torsion of the suspending fibre, which is constantly changing both as to direction and amount, comes to have a larger influence than is desirable upon the results. It is fortunate that the influence of a progressive change of this sort may be largely eliminated by a suitable order of experimentation.

Several tables follow, containing results which seem to warrant the statements with which the paper commences.

In these tables, column *A* gives the number of the experiment in the series. *B* contains the observed galvanometer deflections when the magnet was inactive; *C*, deflections when the magnet was excited. *D* and *E* contain averages of the groups given in *B* and *C*. At the foot of the table is given the general average, and the deduced percentage variation.

Table I. Magnetic force perpendicular to the plates of the condenser. Two condensers used, each consisting of 11 disks of copper 8 cm. in diameter, with plates of mica between them. In this series the condenser which had the greatest normal capacity was placed between the poles of the magnet. An increase in the differential deflection of the needle when the magnet was excited indicates an increase of capacity in this condenser.

TABLE I.

A.	*B.*	*C.*	*D.*	*E.*
1	18			
2	19			
3	18			
4	18	....	18¼	
5	....	22		
6	....	22		
7	....	22		
8	....	20		
9	....	22		
10	....	20		
11	....	22		
12	....	20	....	21
13	18			
14	18			
15	18			
16	19	....	18¼	
17	....	22		
18	....	20		
19	....	22		
20	....	20	....	21

TABLE II.

A.	*B.*	*C.*	*D.*	*E.*
1	30			
2	31	....	30½	
3	....	28		
4	....	28	....	28
5	33			
6	32	....	32½	
7	....	28		
8	....	28	....	28
9	35			
10	34	....	34½	

Table II. Exchanged the places of the condensers used in Table I., the smaller of the two being now placed between the poles of the magnet. Direction of the magnetic force as in Table I. In this series a diminished differential deflection of the needle with the excitement of the magnet shows an increase of capacity in the condenser between the poles.

In Series I. and II. the distance between the poles of the magnet was not observed. These distances probably were not the same, for the pole pieces were removed in changing condensers.

Tables III. and IV. Magnetic force perpendicular to the plates of the single condenser. This was made of two disks of copper eight centimeters in diameter, with a sheet of mica between them. Between the two series of experiments the direction of the magnetic force was reversed. An increase of capacity equal to 3½ per cent is shown in both tables. Hence we conclude that the change in capacity is not reversed in sign with the reversal of the direction of the magnetic force.

TABLE III.

A.	*B.*	*C.*	*D.*	*E.*
1	47			
2	48			
3	47			
4	47	....	47.2	
3	....	46		
4	....	49		
5	....	47½		
6	....	49½		
7	....	48½	....	48.1
8	49			
9	—			
10	47			
11	45½			
12	—			
13	46	....	46.9	
14	....	49		
15	....	51		
16	....	49		
17	....	51		50
18	50			
19	49			
20	51	....	50	
21	....	53		
22	....	53	....	53
24	51½			
25	52	....	51.7	
26	....	55		
27	....	56	....	55.5
28	52½			
29	53	....	52.7	
Average . . .			49.7	51.6

Increase of capacity, 3¾ per cent.

TABLE IV.

A.	*B.*	*C.*	*D.*	*E.*
1	51			
2	54			
3	54			
4	54	....	53.2	
5	....	56		
6	....	56		
7	....	56	....	56
8	54			
9	54	....	54	
10	....	55		
11	....	55		
12	....	55½	....	55.1
13	53½			
14	53½	....	53	
Average . . .			53.4	55.5

Increase of capacity, 3½ per cent.

Tables V., VI., and VII. show the variation of this effect with the intensity of the field. In Table V. the poles were 1 mm. apart; in Table VI., $2\frac{3}{4}$ mm.; in Table VII., $4\frac{1}{2}$ mm. distant from each other.

TABLE V.

A.	*B.*	*C.*	*D.*	*E.*
1	167			
2	166	....	166.5	
3	....	197		
4	....	202	....	199.5
5	175			
6	175	....	175	
Average . . .			170.7	199.5
Increase of capacity, 17 per cent.				

TABLE VI.

A.	*B.*	*C.*	*D.*	*E.*
1	196			
2	193	....	194.5	
3	....	217		
4	....	218	....	217.5
5	190			
6	196	....	193	
Average . . .			193.7	217.5
Increase of capacity, 12 per cent.				

TABLE VII.

A.	*B.*	*C.*	*D.*	*E.*
1	177			
2	185	....	181	
3	....	194	....	192
4	....	190		
5	191	....	191	
6	....	197		
7	....	203	....	200
8	193			
9	185	....	189	
Average			187	196
Increase of capacity, 5 per cent.				

The single condenser used was made of four sheets of tinfoil 6 cm. by 6 cm., with paraffined paper between them. The direction of the magnetic force as in the preceding tables. The capacity was increased in each series; in Table V. about 17 per cent, in Table VI. 12 per cent, and 6 per cent in Table VII.

Tables VIII. and IX. show results obtained by using a single condenser, whose plates were parallel to the lines of magnetic force. The condenser was made of forty copper strips, 6 mm. wide and 6 cm. long,

TABLE VIII.

A.	*B.*	*C.*	*D.*	*E.*
1	32			
2	32	....	32	
3	....	30		
4	....	27½	....	28.8
5	33			
6	33	....	33	
7	....	32		
8	....	33	....	32.5
9	32			
10	28			
11	33			
12	37			
13	34	....	34.7	
14	....	37		
15	....	35		
16	....	33	....	35
17	38			
18	38	....	38	
19	....	37		
20	....	35		
21	....	36	....	36
22	38½			
29	37½			
30	37½	....	37.8	
31	....	37½		
32	....	35		
33	....	37½	....	36.6
34	38½	....	38.5	
Average . . .			35.7	33.8
Decrease in capacity, 5 per cent.				

TABLE IX.

A.	*B.*	*C.*	*D.*	*E.*
1	71			
2	70			
3	69			
4	67	....	69.2	
5	....	65		
6	....	66		
7	....	68		
8	....	68	....	66.7
9	72			
10	73			
11	71			
12	74	....	72.2	
Average . . .			70.7	66.7
Decrease in capacity, 5 per cent.				

insulated by paraffined paper. The poles of the magnet were 10 mm. apart. In both of these tables the establishment of a magnetic field is seen to produce a diminution in the capacity of the condenser of about 5 per cent.

A series of experiments (see Table X.) made with a mica condenser, placed in the field with its plates perpendicular to the lines of magnetic force and with the poles 10 mm. apart, showed that its capacity was increased by about 5 per cent.

TABLE X.

A.	*B.*	*C.*	*D.*	*E.*
1	83			
2	80	....	81	
3	....	88		
4	....	93	....	90
5	91			
6	90	....	91	
7	....	96		
8	....	97	....	96
9	93			
10	92	....	92	
11	....	100		
12	....	100	....	100
13	98			
14	92	....	95	
Average . . .			90	95
Increase of capacity, 5+ per cent.				

It is very difficult in such an investigation to prove the absence of error. It would also seem to be nearly as difficult to imagine a source of error which should reverse its sign, as in Tables III. and IV., when two condensers change places, and yet give consistent results showing an increase of capacity in both cases, — which should also show a change of sign when we pass from the use of condensers whose plates are perpendicular to the lines of force to those whose plates are parallel to those lines, — and, finally, which should change in amount with the intensity of the field.